Protection From Contamination by ^{211}At, an Enigmatic but Promising Alpha Emitter

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Short communication

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Abstract

Purpose

^{211}At, a promising alpha emitter, can easily volatilize and contaminate the environment. To safely manage this unique alpha emitter, we investigated the permeability of four types of plastic films and gloves against ^{211}At and identified suitable materials to avoid contamination by ^{211}At.

Methods

Four types of plastic films, polyethylene, polyvinylidene chloride, polyvinyl chloride, and a laminated film, and two types of rubber gloves, latex and nitrile, were examined. Small pieces of filter paper were covered with these materials, and a drop containing 100 kBq of ^{211}At was placed on them. The radioactivity of pieces of filter paper under the materials was evaluated by measuring counts using a gamma counter and obtaining autoradiograms 3.5 h later. These experiments were also performed using ^{225}Ac, ^{125}I, ^{111}In, ^{201}Tl, and ^{99m}Tc.

Results

^{211}At solution easily penetrated polyethylene, polyvinyl chloride, and latex rubber. Similar results were obtained for ^{125}I, while other radionuclides did not penetrate films or gloves. These results suggest that halogenic radionuclides under anionic conditions are likely to penetrate plastic films and rubber gloves.

Conclusion

Our evaluation revealed that, when ^{211}At solution is used, the protection by polyvinylidene chloride, a laminated film, or nitrile rubber would be more effective than that by polyethylene, polyvinyl chloride, or latex rubber.

Introduction

The recent outbreak of coronavirus disease 2019 (COVID-19) has drawn people's attention to the protection from virus contamination; however, protection from radioactive contamination has been essential for workers in the field of nuclear medicine because the use of unsealed radioactive materials exposes them to unnecessary radiation. Protection measures against radionuclide contamination are sometimes different from those against viruses [1]. Moreover, the protection measures depend on the type of radionuclide. Currently, radionuclide therapy, in which particle-emitting radionuclides are used, is gaining popularity. In particular, radionuclide therapy using alpha emitters has attracted considerable attention from researchers and physicians in the field of nuclear oncology. Protection from contamination by alpha emitters is crucial because alpha particles can severely damage tissues in which they accumulate. Although alpha particles themselves can be blocked by a sheet of paper, the isolation of alpha emitters is not always easy. We recently pointed out that a solution containing ^{211}At, a promising alpha emitter for targeted alpha therapy (TAT), can easily penetrate latex gloves, which are the most effective personal protective equipment (PPE) against COVID-19[2]. When we work with radioactive materials, we put on PPE and wrap radioactive materials by plastic films to properly isolate them and avoid accidental internal radiation exposure. In this study, we investigated the ability of four types of plastic films and two types of gloves to protect against contamination due to ^{211}At, compared with some other radionuclides, for the safe management of this enigmatic alpha emitter.

Materials And Methods

The following radionuclide solutions in addition to [^{211}At]NaAt solution were used to evaluate the permeability of plastic films and rubber sheets: [^{225}Ac]Ac$(NO_3)_3$, [^{125}I]NaI, [^{111}In]$InCl_3$, [^{201}Tl]TlCl, and [^{99m}Tc]$NaTcO_4$.

^{225}Ac is also a promising alpha emitter for TAT, and this radionuclide acts as a trivalent cation in a solution. ^{125}I is a halogen that acts as an anion in a solution. ^{111}In is a photon emitter that acts as a trivalent cation in a solution. ^{201}Tl is a photon emitter with a main energy of 70.3 keV, which is similar to that of characteristic X-rays emitted from ^{211}At [3]. ^{201}Tl acts as a cation in a solution. ^{99m}Tc is a photon emitter that acts as an anion in the form of [^{99m}Tc]TcO_4^- in a solution. [^{211}At]NaAt was supplied by the RIKEN Institute (Wako, Japan). [^{225}Ac]Ac$(NO_3)_3$ was purchased from Global Morpho Pharma (La Chapelle-sur-Erdre, France). [^{125}I]NaI was purchased from PerkinElmer (Waltham, MA, USA). [^{111}In]$InCl_3$ and [^{201}Tl]TlCl were purchased from Nihon Medi-Physics (Tokyo, Japan). [^{99m}Tc]$NaTcO_4$ was purchased from FUJIFILM Toyama Chemical (Tokyo, Japan).

Four types of plastic films and two types of rubber gloves were tested. Polyethylene (30 μm), polyvinylidene chloride (11 μm), and polyvinyl chloride (8 μm) and laminated films of polypropylene, ethylene vinyl alcohol copolymer (EVAL™, Kuraray, Tokyo, Japan), and polyethylene (104 μm) were used as plastic films. The numbers in parentheses are the film thicknesses. The first three plastic films are commercially available to wrap perishable food materials and keep them fresh. The laminated film was developed to pack dried bonito flakes so that they are not damaged by oxygen and high humidity. As rubber sheets, pieces of latex and nitrile rubber gloves were used. These gloves are currently used as PPE against COVID-19[4]. The thickness of each glove was more than 130 μm for latex and 70 μm for nitrile.

A three centimeter square piece of filter paper was covered by a sheet of plastic film or a piece of rubber cut out from a rubber glove. Fifty microliters of radionuclide solution whose radioactivity was adjusted to 100 kBq was dropped on a plastic film or rubber (Figure 1). The plastic film or rubber was covered by a plastic Petri dish to minimize the evaporation of the radioactive solution. Each piece of filter paper under the plastic film or rubber was picked up 3.5 h later. This interval is half the half-life of ^{211}At. These pieces of filter paper were placed on imaging plates (FUJIFILM, Tokyo, Japan) for 5 min and approximately 15 h. The imaging plates were scanned with an imaging plate reader (FLA-7000; FUJIFILM, Tokyo, Japan). The acquired images were analyzed using the ImageJ software (U.S. National Institutes of Health, Bethesda, MD, USA). The radioactivity of these pieces of filter paper was also measured using a gamma counter (2480 Wizard^2; PerkinElmer, Waltham, MA, USA). These experiments were repeated three times for each radionuclide.

Results

When the [^{211}At]NaAt solution was dropped on pieces of plastic film and sheets of rubber, strong radioactivity was detected in the filter paper under polyethylene film, polyvinyl chloride film, and latex rubber, in that order. No hot spots were detected in the pieces of filter paper under polyvinylidene chloride film, the laminated film, or the nitrile rubber (Figure 2).

When the [^{225}Ac]Ac(NO_3)$_3$ solution was dropped on the materials, no significant radioactivity was detected in each piece of filter paper under films and rubber (Figure 3, Supplementary Figure 1).

When the [^{125}I]NaI solution was dropped on the materials, strong radioactivity was detected in pieces of filter paper under polyethylene film, polyvinyl chloride film, and latex rubber, in that order. No significant radioactivity was detected in pieces of filter paper under the polyvinylidene chloride film, the laminated film, or the nitrile rubber sheet (Figure 4). These results are similar to those of the [^{211}At]NaAt solution.

When [^{111}In]InCl_3, [^{201}Tl]TlCl, and [^{99m}Tc]NaTcO_4 solutions were dropped on the materials, no significant radioactivity was detected in each piece of filter paper even after 15 h of exposure (Supplementary Figures 2, 3 and 4).

The radioactivity of pieces of filter paper is summarized in Figure 5, and the originally measured data are shown in the Supplementary Table.

Discussion

^{211}At, a promising alpha emitter for TAT, is popular in Japan because of its wider availability. Many researchers in Japan have been engaged in studies using radionuclides. However, this element is regarded as an enigmatic element[5] and most of its characteristics remain unclear. Previous studies have reported that ^{211}At can easily volatilize and contaminate the environment [6]. Therefore, strict protection and shielding measures are essential when using this enigmatic alpha emitter. In this study, we revealed that the permeability of the [^{211}At]NaAt solution is dependent on the type of shielding material. ^{225}Ac is another popular alpha emitter, and the [^{225}Ac]AcCl_3 solution penetrated films and rubber little. Since the numbers of alpha particles emitted during the single decay of ^{211}At and ^{225}Ac atoms are one and four, respectively, ^{225}Ac is a stronger alpha emitter than ^{211}At. Considering these findings, we believe that the penetration of the [^{211}At]NaAt solution of films and rubber was not induced by the direct destruction of materials by emitted alpha particles. The penetration depends on the chemical properties of the shielding materials. ^{225}Ac, which is cationic in a solution, and other cationic radionuclides ^{111}In and ^{201}Tl also failed to penetrate the shielding materials. In contrast, ^{125}I, which is a halogen and is anionic in [^{125}I]NaI solution as ^{211}At, showed a similar trend to that of ^{211}At. However, another popular radioactive anion, [^{99m}Tc]TcO_4^-, did not penetrate the material. These results suggest that halogenic radionuclides under anionic conditions are likely to penetrate plastic films and rubber.

Among the materials examined in this study, two types of plastic films made of polyethylene, polyvinyl chloride, and latex rubber glove were penetrated by ^{211}At, and they were considered ineffective in protecting the contamination due to ^{211}At. However, the polyvinylidene chloride film, the unique laminated film, and the nitrile rubber glove were resistant to the penetration by the [^{211}At]AtNa solution. Although the details of the differences in chemical properties of materials between these two groups, easily permeable and non-permeable for ^{211}At, were unrevealed, the permeability of the [^{211}At]AtNa solution was correlated with that of gas or water according to open data [7]. It is difficult to clearly explain the mechanism of the permeability of ^{211}At for plastic films and rubber gloves through these data, and further investigation is needed to determine the optimal methods to protect the contamination by ^{211}At. However, polyethylene is cheap, and bags made of this material are sold for radioactive waste stuffs, and they are actually used in experiments with ^{211}At [8]. Latex rubber gloves are also the most popular PPE. Considering such situations, warnings should be given to people who deal with the ^{211}At solution. Hence, we must put on nitrile gloves and wrap or cover specimens with polyvinylidene chloride film or a laminated film while working with compounds including ^{211}At to avoid unnecessary internal radiation exposure.

Conclusion

Our preliminary experiments indicated that the ^{211}At anion can easily penetrate at least two types of plastic films, polyethylene and polyvinyl chloride, and latex rubber. The permeability of ^{211}At may depend on its chemical properties as a halogen that becomes an anion in a water solution. When we deal with the ^{211}At anion, we must put on nitrile gloves and wrap or cover specimens using a polyvinylidene chloride film or a laminated film.

The List Of Abbreviations

COVID-19: coronavirus disease 2019

PPE: personal protective equipment

TAT: targeted alpha therapy

Declarations

Ethics approval and consent to participate: Not applicable since this study did not involve human participants or animals.

Consent for publication: No individual person's data are included in this study.

Availability of data and material: The data in this study are available from the corresponding author upon reasonable request.

Competing interests: The authors declare no conflicts of interest.

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Authors' contributions: All authors contributed to the study conception, and the first draft of the manuscript was written by Kazunobu Ohnuki and Hirofumi Fujii, and all authors read and approved the final manuscript.

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Figures

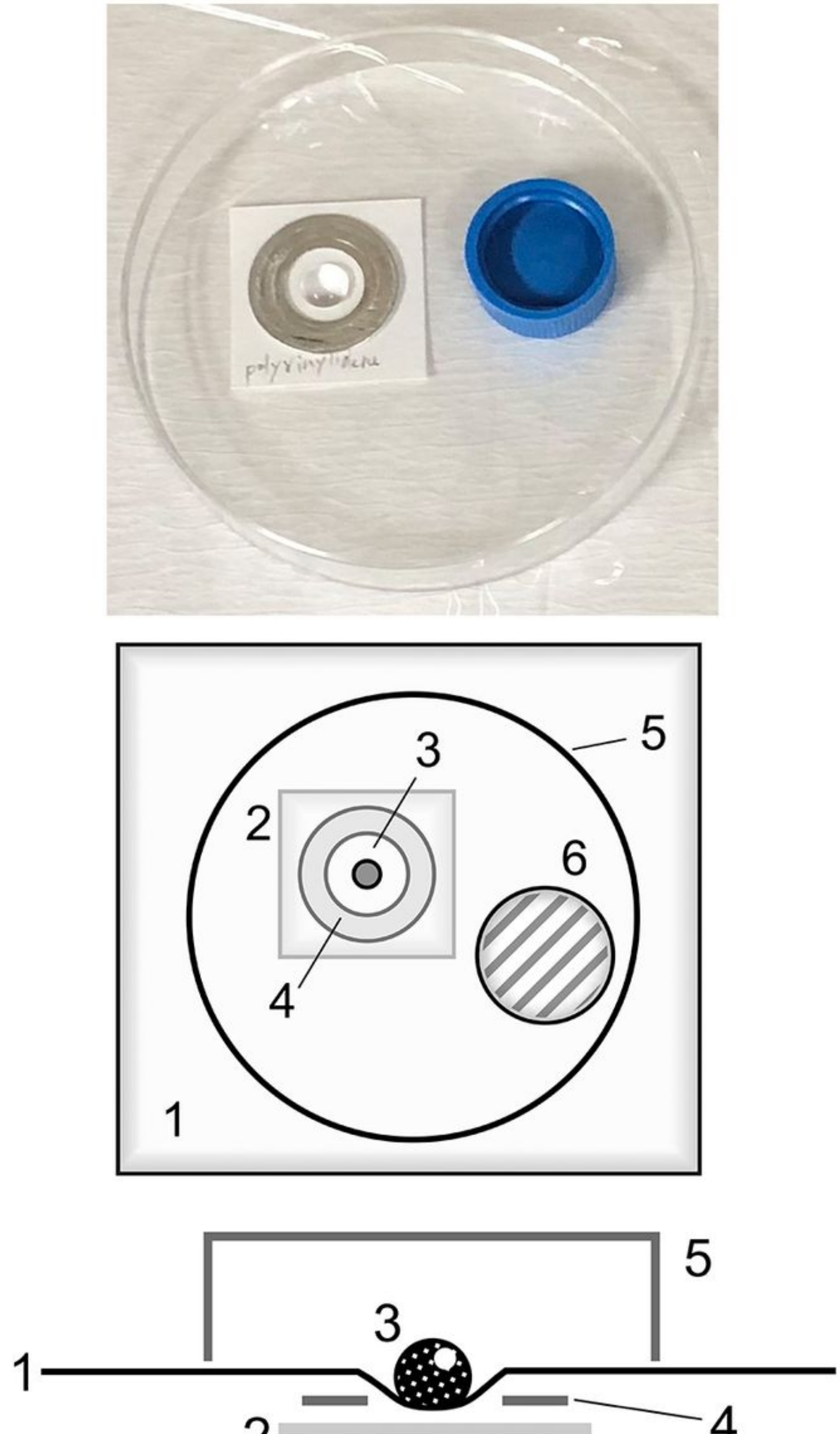
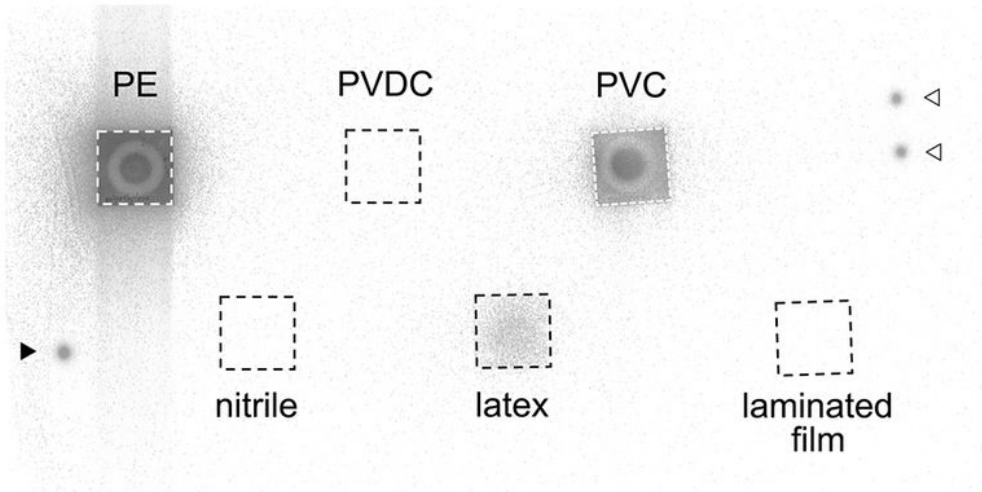


Figure 1

The schema of the experiments to evaluate the permeability of films and rubber. a The photograph indicating the configuration of a radioactive drop, sheet of film or rubber, piece of filter paper, and so on. b The schema of the configuration. 1: film or rubber, 2: filtering paper, 3: radioactive drop, 4: aluminum ring (to keep the drop at the same position), 5: plastic plate (to avoid contamination by volatilized radionuclides), 6: water (to avoid vaporization of drop). c The schema of the section of the configuration.



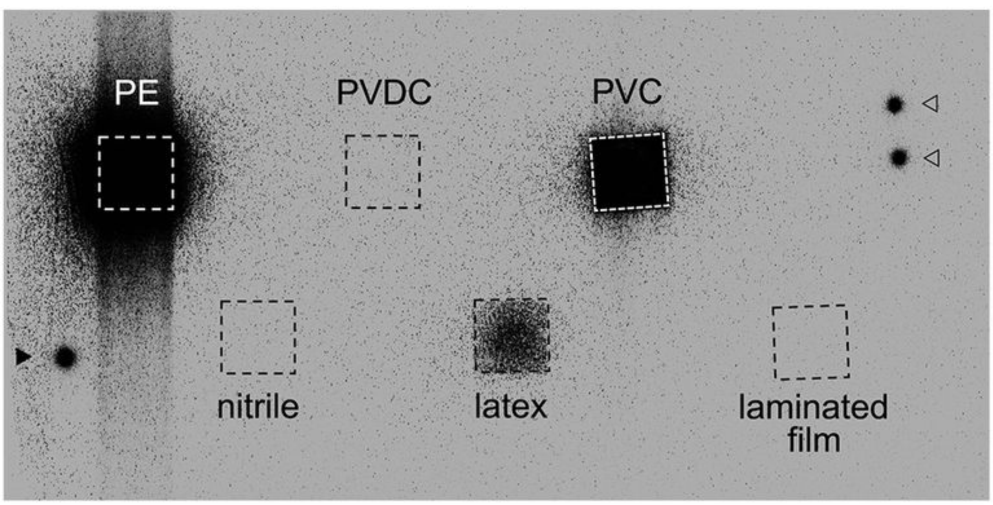


Figure 2

The permeability of the [211At]NaAt solution through films and rubber. The autoradiogram of pieces of filter paper obtained after 5-min exposure to imaging plates. PE: polyethylene, PVDC: polyvinylidene chloride, PVC: polyvinyl chloride. a Full scale image, b overexpressed image. 125I drops sealed by polyvinylidene chloride film were also put as markers. The arrowhead indicates a 125I drop with 0.1 kBq and the open arrowheads indicate 125I drops with 0.05 kBq.

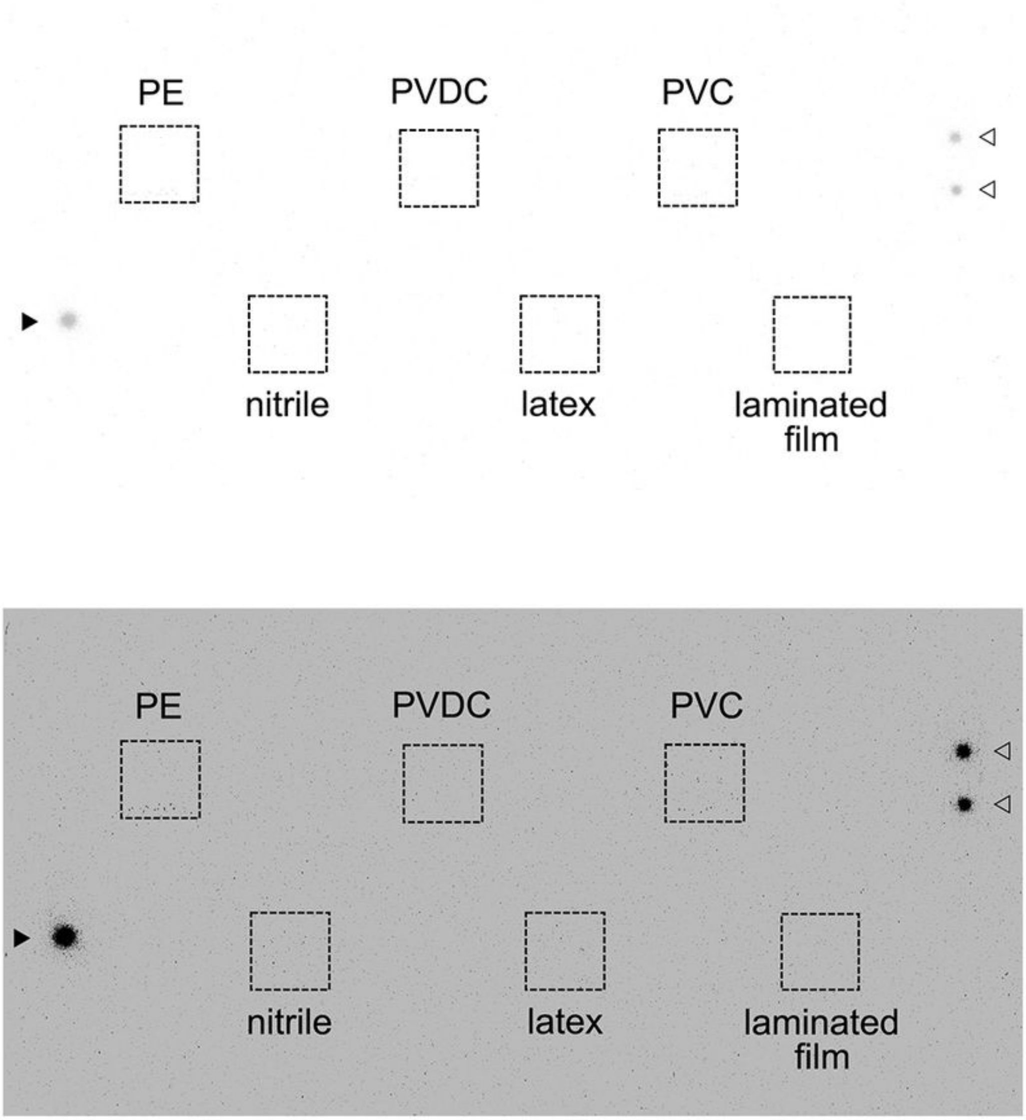


Figure 3

The permeability of the [225Ac]Ac(NO3)3 solution through films and rubber. The autoradiogram of pieces of filter paper obtained after 5-min exposure to imaging plates. a Full scale image, b overexpressed image.

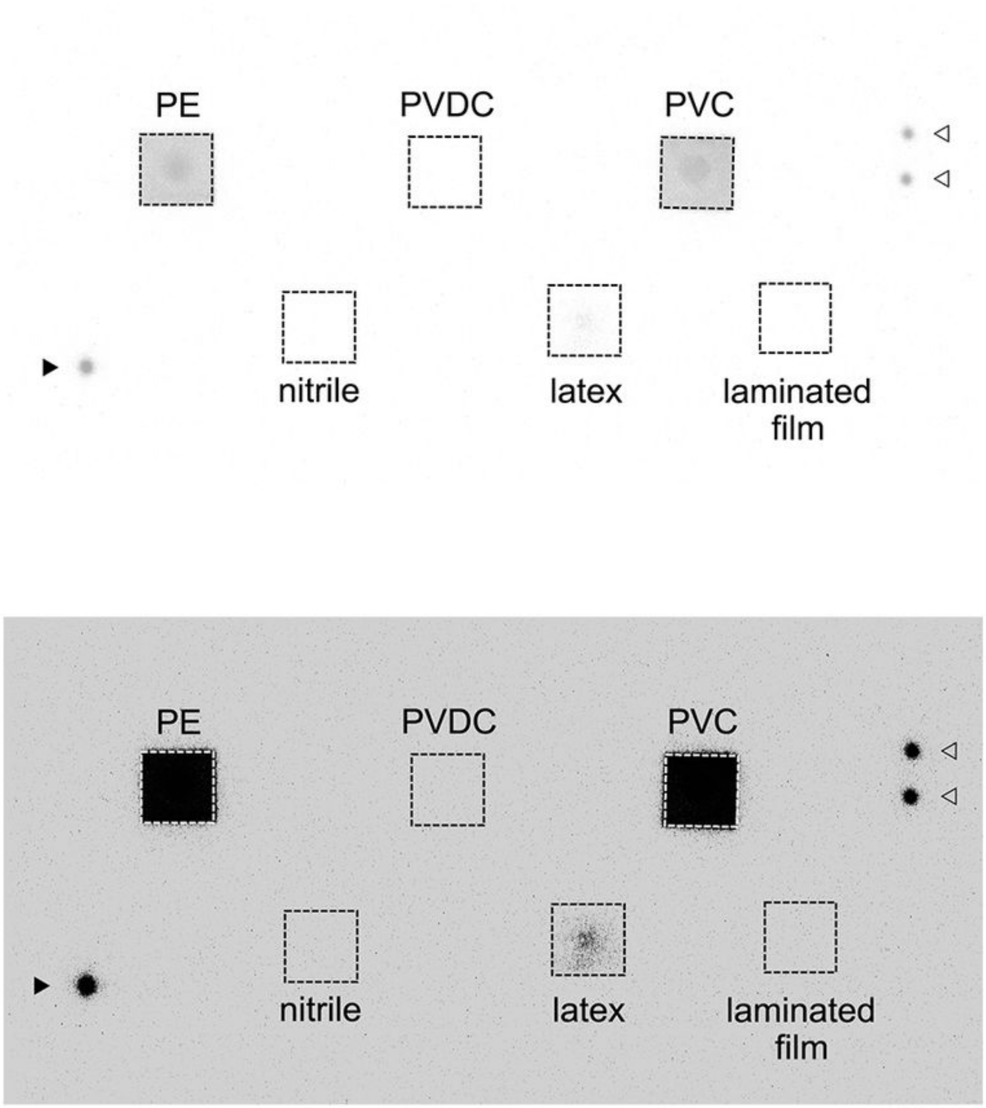


Figure 4

The permeability of the [125I]NaI solution through films and rubber. The autoradiogram obtained after 5-min exposure to imaging plates. a Full scale image, b overexpressed image.

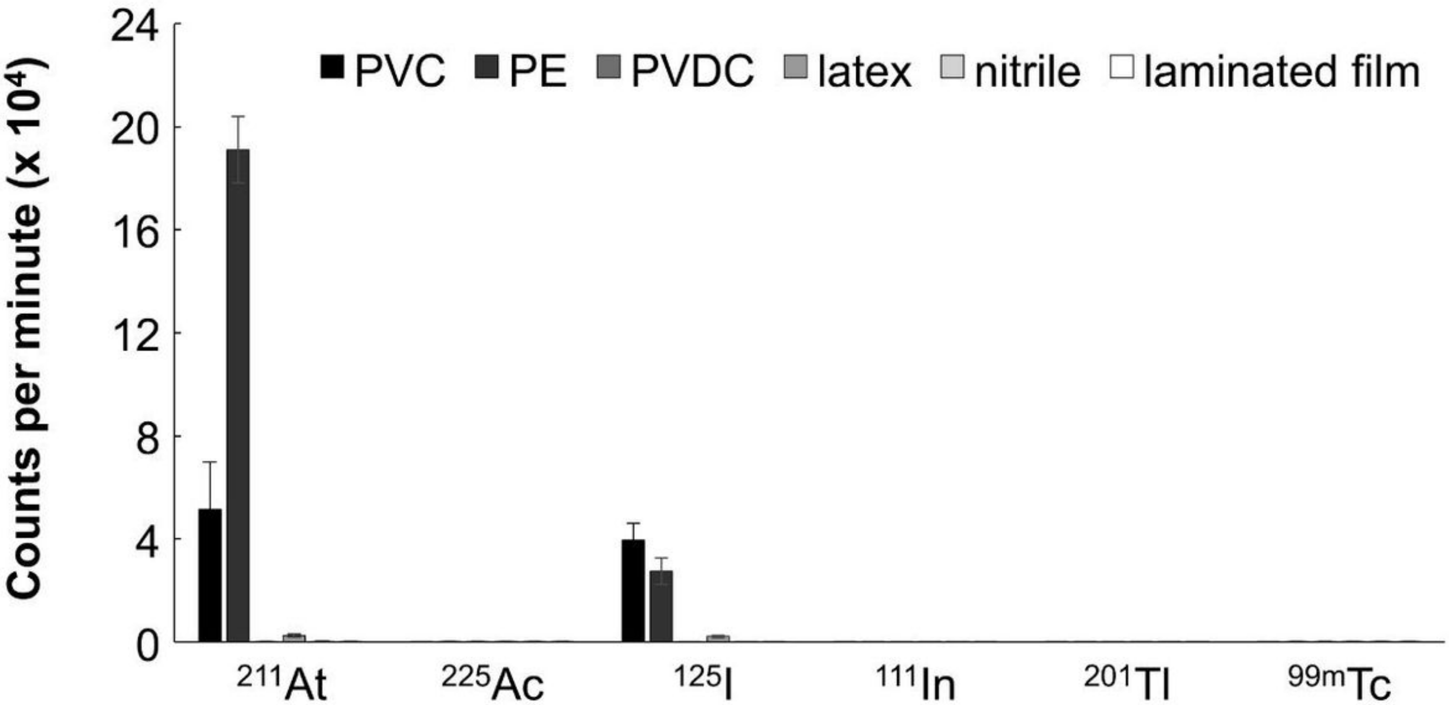


Figure 5

The radioactivity of pieces of filter paper counted by a gamma counter. The counts after attenuation correction are shown.

Supplementary Files

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- SupplementaryInformation.pdf